Top Quark Cross Section in electron + jets Channel using Topological Method and Neural Network in Run II data of the DØ experiment at the Tevatron

by

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Introduction

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Tevatron and DØ Detector

The Tevatron collider, located in the Fermi National Accelerator Laboratory in Illinois, USA. , accelerates both the protons and antiprotons to 1 TeV and provides a collisions at the center of mass energy of almost 2 TeV . Figure 2.1 shows the Fermilab accelerator chain. DØ is one of the collider experiment at Tevatron. DØ detector is designed to study the products of this proton and antiproton annihilation and took its first data in the period 1992-1996, called Run I, with the center of mass energy 1.8 TeV using 6x6 proton and antiproton bunches and 3.5 μs interval between the crossings, which produced the luminosity of the order 10^{31} $cm^{-2}s^{-1}$ and collected about 100 pb^{-1} data. Between 1996 and 2001 the Tevatron have been upgraded to obtain the higher center of mass energy and luminosity, called Run II. For the first phase, Run IIa, the center of mass energy has been raised to 1.96 TeV using 36x36 proton and antiproton bunches and 396 ns between crossings. The luminosity will be $2x10^{32}$ $cm^{-2}s^{-1}$. After collect 4 fb^{-1} data, with a short shutdown period, the second phase, Run IIb, will continue with 100x100 proton and antiproton bunches with 132 ns between crossings and the luminosity will be $5x10^{32}$ $cm^{-2}s^{-1}$. Currently the peak luminosity is $4.4x10^{31}$. The expected

Figure 2.1: The Fermilab accelerator chain

integrated luminosity for Run II will be 6-11 fb^{-1} [1].

2.1 Accelerator

The Run II at Fermilab began in March 2001 and it requires major changes to the accelerator complex [2] [3] [4] and the detector [5]. The most notable changes include the construction of the new main Injector, which replaces the Main Ring from Run I, the Recycler Ring, which will be used for storing antiprotons produced in the $\overline{p}$ source as well as the antiprotons remaining in the Tevatron after a physics store and the increased Tevatron beam energy from 900 GeV to 980 GeV with operating the Tevatron as a 36x36 bunch collider. The proton source, consists of a 25 KeV of the negative charged hydrogen ions, is accelerated to 750 KeV in Cockcroft-Walton accelerator and bunched and led into a 150 m long linear accelerator(LINAC), which accelerates the ions to 400 MeV . Using carbon foil strips, protons are selected and led into the Booster synchrotron which accelerates their energy to 8 GeV . The Main Injector should provide a higher repetition rate to support antiproton production while simultaneously providing protons for fixed-target operations. New main injector has multiple operating modes including: providing up to 5x10^{12} 120 GeV protons per pulse for antiproton production with 2.0 second cycle time; accelerating protons and antiprotons to 150 GeV for injection into the Tevatron, transferring 8 GeV antiprotons from the Accumulator to the Recycler; providing 8 GeV (and eventually 120 GeV) protons for neutrino production. The antiprotons are produced with 2.4 second cycle time by colliding 5x10^{12} 120 GeV protons per pulse on a nickel target in main Injector, Due to the antiproton production is very important factor for Run II, lattice modification of antiproton target and stochastic cooling tank upgrades in the Debuncher and Accumulator has been done to take advantage of the higher repetition rate allowed by the Main Injector. The 8 GeV antiprotons from the production target are collected, debunched in the Debuncher with stochastically cooling system and transferred to the Accumulator. In the Accumulator, they will be stacked and cooled into a 'core'. The stacking rate of the antiproton varies from at 11x10^{10}/hr and falling to 6x10^{10}/hr depends on the stack size with 140x10^{10} of the typical stack intensity. The Recycler is a combined-function permanent magnet storage ring in the Main injector tunnel and storing 8 GeV antiprotons. The antiprotons remaining in the Tevatron after a store will be recycled by decelerating them in Tevatron and Main Injector and added to an existing Recycler stack. This recycled antiprotons give a benefit for antiproton production rate by transferring small stacks from the Accumulator. The Recycler will be integrated into the collider operations by the end of 2003. 7 bunches with 53 MHz of the proton beams in Booster are transferred into the Main Injector, accelerated to 150 GeV and coalesced into one bunch and injected into the Tevatron. The procedure will be repeated with 36 bunches separated by 396 ns and they will be making the Tevatron central orbit. The antiproton beam made up of sets of 7 bunches with 53

Figure 2.2: D0 detector side view

MHz from Accumulator, transferred to the Main Injector and accelerated to 150 GeV . They will be coalesced into 4 bunches and injected into the Tevatron with 36 repeated times and they will be circulating in the Tevatron in separated helical orbit with protons beams. The proton and antiproton beams will be accelerated to 980 GeV . Finally they will collide at the interaction regions at BØ and DØ. The store of the collision will be last for about 1 luminosity lifetime(12 $\sim$ 14 hours). The luminosity will be discussed in Section 2.2.4.

2.2 DØ detector

The DØ Detector consists of 3 major components which is the Tracking system, Calorimeter and Muon System. For Run II DØ Detector was upgraded in order to pursue the forefront physics with the new high luminosity Main Injector environment [6].

2.2.1 Tracking System

The tracking system in DØ detector consists of an inner Silicon Microstrip Tracker (SMT), surrounds by an Central Scintillating Fiber Tracker(CFT) and 2 T superconducting solenoid. Finally the Scintillator Preshower Detector is located in the outside of the solenoid. With upgraded tracking system, we can achieve these goals;momentum measurement by the introduction of a solenoidal field; good electron identification and e/ϕ rejection; tracking over a large range in pseudorapidity($\eta \approx \pm 3$); secondary vertex measurement for identification of b-jets from Higgs, Top physics and for b-physics; first level tracking trigger; fast detector response to enable operation with a bunch crossing time of 396 ns; radiation hardness for the high luminosity in Run II [6] [7].

Silicon Microstrip Tracker

The silicon Microstrip Tracker(SMT) is the first set of detectors nearest the collision of $p\overline{p}$ in DØ and provides the high resolution part of tracking system. Based on several Run II collider requirements, the SMT was designed. The luminosity determines a scale for the radiation damage expected over the life of the detector, which in turn dictates the operating temperature($< 10^o$ C) and the long luminous region determines the length scale, and motivates our hybrid and barrel design. The crossing interval determines the design parameters for the electronics and readout. Since collider interaction points is extended, with σ_Z of 25 cm, it is hard to deploy detectors such that the tracks are generally perpendicular to the detector surface for all η, which forces us to a hybrid system with barrel detectors measuring primarily the $r - \phi$ coordinate and disk detectors which measure $r - z$ as well as $r - \phi$. Therefore vertices for high η particles are reconstructed in three dimensions by the disks, and vertices of particles at small η are determined by the barrels.

Fig. **??** shows the design of the interspersed disk and barrels. To minimize extrapolation errors which require a small separation between disks and a dead region between barrels which is introduced by each plane of disks which lowers the overall efficiency of the detector, the design of SMT puts a premium on minimizing the gap between barrels sections by a compromise between vertex resolutions at large η and efficiency at small values of η and provides flexibility by the modular design. Our baseline design includes six barrels sections with the more expensive 90 degree double metal technology detectors used for the central modules:

- 6 barrel segments in z.
- 4 detector layers per barrel
  - Layer 1 (innermost) and 3 are divided into the central and end regions and consists of:
    - double-sided detectors (axial and 90^o z-strips) in the central 4 barrel segments.
    - single-sided detectors (axial strips) in the out most barrel segments at each end.
  - Layers 2 and 4 are double-sided detectors (axial strips and 2^o stereo strips)
- 12 small diameter, double-sided "F" disks (30^o stereo, 4 sandwiched between barrel segments)
- 4 large diameter, single-sided "H" disks(15^o stereo)

The 12 cm long barrel segments are separated by 8 mm gaps containing F disks and four more F disks are located at each end of the barrel. The H disks are located at $| z | \approx 110$ cm and 120 cm. The individual channel for each layer for barrel detectors is $\sim$ 46k, 83k, 92k and 166k and 258k for F disks and 147k for H disks. The number of total channel is $\sim$ 793k.

The barrels and the F disks consist of 50 and 62.5 μm pitch silicon microstrip detectors, 300 μm thick, allowing the identification of a 10 μm of a spatial resolution and the small angle of stereo detectors provide the pattern recognition necessary to resolve tracks from b decays within jets. The 90 degree detectors provide resolution in $r - z$ at the vertex of 100 μm, providing the identification of decay fragments by impact parameter in the $r - z$ plane. Each strip has an integrated coupling capacitor and a polysilicon bias resistor which has been shown to be sufficiently radiation hard. F disks consists of 12 double-sided detectors which have $\pm$ 15^o stereo strips. Figs. **??** and **??** show cross sectional views in the $r - \phi$ plane of the barrel and F disks.

The SVX II front end readout chips are used on a kapton high density circuit(HDI) which is laminated onto a 300 μm thick beryllium plate and glued to the surface of the detector and the end of the HDI consists of a kapton strip cable which carries signals and bias voltages to the outer radius of the detector($\approx$ 18 cm) where a connection to a long($\approx$ 8 m) low mass microstrip cable is made. These cables carry the signals to the port cards located on the DØ support platform.

The mechanical structure requires a precise and stable support for the individual barrel and disk detectors with sufficient coolings for heat generated in the SVX II chips and allow for the necessary cable paths for external connections. For the barrels the basic mechanical unit is the ladder and each ladder supports two detectors wire-bonded together, forming a 12 cm long unit with the SVX II readout at one end with Rohacell-carbon fiber support rails which provide extra rigidity to the ladder. The ladders are mounted on beryllium bulkheads which support at both ends of the ladder and provide cooling at the readout end by means of an integrated coolant channel. The F disks consist of a single F disk detector with SVX II readout at the outer radius and are mounted in the 8 mm gap between the barrel segments. Water cooling is via a beryllium cooling channel which supports the modules at the outer radius.

The barrels and disks are supported by a double-walled carbon half-cylinder with zero thermal expansion. The half-cylinder has a length of 1.66 m and an outer radius of 15.3 cm. The cooling of ladders is important to avoid excessive radiation damage to the inner silicon layer and is found to be a maximum temperature in the silicon of 10^o C.

A silicon track trigger preprocessor is built to provide the SMT information in the Level 2 trigger which can provide the triggering on tracks displaced from the primary vertex, as well as sharpening the p_T threshold of the Level 2 track trigger and of the electron and jet triggers at Level 3.

Cental Fiber Tracker

The central Fiber Tracker(CFT) surrounds the silicon vertex detector and covers the central pseudorapidity region with two main functions. First, with Silicon Microstrip Tracker, the tracker enables track reconstruction and momentum measurement for all charged particles within the range $\mid \eta \mid < 2.0$ and second, the CFT provides fast "Level 1" track triggering within the range $\mid \eta \mid < 1.6$. Combining information from the tracker with the muon and preshower detectors, triggers for both single muons and electrons will be formed at Level 1 and these triggers will be critical to take full advantage of the physics opportunities available with the Main Injector. The CFT consists of 8 layers and each layer contains a doublet of one layer of axial fibers and one layer of $\pm 3^o$ stereo fibers of 830 μm diameter with 870 μm spacing and offset by half the fiber spacing. The carbon fiber cylinders are used to support the doublet of the fibers. The basic detection element is the multi-clad scintillating fiber and the inner polystyrene core is surrounded by a thin acrylic cladding, which in turn is covered by a thin fluoro-acrylic cladding. These three materials have indices of refraction of 1.59,1.49, and 1.42, respectively. The addition of the second cladding increases the light trapping by about 70% with respect to single-clad fibers and improves the mechanical robustness of the fibers. The typical fiber diameter is 835 μm and each cladding is 15 μm thick. The polystyrene core of the fibers is doped with 1% p-terphenyl (PTP) and 1500 ppm of 3-hydroxyflavone (3HF) and the fiber scintillates in the yellow-green part of the visible spectrum with a peak emmision wavelength near 530 nm. With this configuration the position resolution can be achieved about ≈ 100 μm in rϕ. The CFT has a total of about 77,000 channels and the fibers are up to 2.5 m long and the light is piped out by clear fibers of length 7-11 m to the visible light photon counter(VLPC) which is in cryostat outside the tracking volume and maintained at 9^o K. The VLPC is the solid state device with pixel size of 1 mm, which matched to the fiber diameter. Especially the VLPC is ideal for fiber tracker because it has a fast risetime, high gain and excellent quantum efficiency. This technology required extensive testing to make the characterization of the thousands of channel of VLPC and the setup of a cosmic ray test stand with fully instrumented fibers. The measured photoelectron yield,a critical measure of the system performance, was found to be 8.5 photoelectron per fiber when 99.5% of the thermal noise was below a threshold of one photoelectron.

Superconducting Solenoid

The superconducting solenoid, which is 2.73 m in length and 1.42 m in diameter, provides a 2 T magnetic fields to help the charged particle momentum measurement. The superconducting (SC) solenoid, built by Toshiba Corp. in Yokohama, Japan, a two layer coil with mean radius of 60 cm, has a stored energy of 5MJ and inside the tracking volume the value of sin$\theta \times \int B_z dl$ along the trajectory of any particle reaching the solenoid is uniform to within 0.5 %. This uniformity is achieved in the absence of a field-shaping iron return yoke by using two grades of conductor with higher current density near the ends of the coils. From the value of the field and the space point precision provided by SMT and CFT, we expected the momentum resolution of $\delta p_T/p_T = 0.002 p_T$ in GeV . The SC coil and cryostat is about 1.1 radiation lengths. The cryogenic plant supplies LHe for both the solenoid and the visible light photon counter(VLPC) readout devices.

Preshower detectors

The central preshower detector(CPS) is designed to help electron identification and triggering as a tracker by providing precise position measurements and to correct electromagnetic energy for effects of the solenoid as a calorimeter by early energy sampling. The cylindrical detector is placed in the 51 mm gap between the solenoid coil and the central calorimeter cryostat at a radius of 72 cm and covers the region -1.2 $< \eta <$ 1.2. The central and forward preshower detectors (CPS and FPS) consists of triangular scintillator strips with axial layer and 20^o stereo layer and wavelength shifter readout(WLS). Cross-sectional end and side views of the detector are shown in Fig. **??**. With a lead absorber tapered in Z before the detector, the total radiation lengths of the material for the solenoid and lead is 2.

Use of preshower information with the fast energy and position measurements helps to electron trigger at the trigger level. The axial layer of the preshower is used in the level 1 electron trigger and provides a factor of 3-5 reduction in the trigger rate by applying a pulse height cut and requiring coarse position-matching with tracks. In off-line analysis, the early sampling of the showers and the good position resolution of the detector will provide additional means for identifying electrons and therefore enhances the capability for tagging $b-$quark jets through their semi-electronic decays.

Each layer consists of 270 cm long 8 octants and WLS fibers are split at z=0 and connected to the clear fibers at both ends of each octant. The fiber splitting at z=0 effectively halves the occupancy for each channel and makes the detector less vulnerable to high rates. The clear fibers from each end of the octants will be grouped together to form one bundle. Preshower has 24 octants with 48 clear-fiber bundles and gives a total of 7680 readout channels for the detector.

The scintillation light from the preshower detector will be transported over 10 m long clear light-guide fibers to the VLPC. VLPC signals are split into two channels each by special chips designed for the preshower to allow for fast trigger pick-off and to effectively extend the dynamic range of the readout system and finally sent to the SVX II chips for amplification and digitization.

The DØ Forward Preshower Detector(FPS) enhances our electron identification capability by making precision measurements of the particle trajectories using dE/dx and showering information collected just upstream of the calorimeter of the calorimeter in forward region. With integrate FPS information we can reduce the Level 1 output rate by a factor of 2-4 (3-7 for Level 2) with no significant reduction in efficiency. In addition, we can have a substantial improvements in offline electron identification and $\gamma\pi^0$ separation with FPS information. Two FPS detectors cover the pseudorapidity range $1.4 <\mid \eta \mid< 2.5$ with one detector mounted on the inner face of each of the End Calorimeter (EC) cryostats and in order to make the most effective use of the limited amount of available space in the region, the detectors is made to conform to the outer shell of the cryostats.

The FPS consists of the triangular scintillator strips with embedded wavelength-shifting fibers, read out by VLPC as that being used in CPS, and a layer of lead absorber of two radiation length thick sandwiched between two active scintillator planes with each scintillator plane consisting of one u and one v sub-layer. The FPS is segmented longitudinally into four structurally distinct layers with consisting of eight azimuthal wedges or modules and each modules will subtend 45^o (one octant) in ϕ with both a u and a v scintillator sub-layers. The central 22.5^o of each module consists of active scintillator volume and the remaining $\approx 11^o$ on either side of the active region provides space and mechanical support for routing the WLS fibers from the ends of the scintillator strips, which are oriented perpendicular to the radial edge defined by the active volume of the modules, to the outer radius of the detector. The modules positions in successive is staggered by 22.5^o layers in order to cover the full azimuthal angle.

The connectors that couple to WLS fibers on the detector end and clear transmission fibers on the other will be mounted at the end of each fiber-routing channel at the periphery of the detector and the clear fiber is routed about the circumference of the FPS and down to the platform below the detectors where the VLPC are housed.

2.2.2 Calorimeter

DØ calorimeter was designed extremely well for Run I and is not changed for Run II. DØ calorimeter employs liquid argon as the active medium which was supported by the unit gain of liquid argon, the relative simplicity of calibration, the flexibility offered in segmenting the calorimeter into transverse and longitudinal cells, the good radiation hardness, and the relatively low unit cost for readout electronics. However the choice of liquid argon included the complication of cryogenic systems; the need for relatively massive containment vessels (cryostat) which give regions of uninstrumented material; and the inaccessibility of the calorimeter modules during operation. For the degree of access to the Central Detectors within the calorimeter cavity, the calorimeter consists of the central calorimeter(CC) which covers roughly $\mid \eta \mid <= 1$ and a pair of end calorimeters(EC - ECN(north) and ECS(south)) which extends the coverage out to $\mid \eta \mid \approx 4$. The boundary between CC and EC was chosen to be approximately perpendicular to the beam direction to introduce less degradation in missing transverse energy($\not{E}_T$) than one in which the EC's nest within the CC shell with a boundary approximately parallel to the beams. The dimension of the calorimeters was determined by the constraints imposed by the size of the experimental hall, the need for adequate depth to ensure good containment of shower energy, the requirements of magnetic measurement of muon momenta outside the calorimeter, and the need for sufficient tracking coverage in front of the calorimetry. With this consideration the calorimeter has three distinct types of modules in both CC and EC: an electromagnetic section (EM) with relatively thin uranium absorber plates, a fine-hadronic section with thicker uranium plates and a coarse-hadronic section with thick copper or stainless steel plates. This coarse sections allow sampling of the end of hadronic showers while keeping the density high which makes the outer radius small. Except at the smallest angles in the EC, several(16 or 32) modules of each type are arranged in a ring. The modular designed with units of workable size without creating undue complications from degraded response near module boundaries. At $\eta = 0$, the CC has a total of 7.2 nuclear absorption lengths(λ_A) and at the smallest angle of the EC, a total of 10.3 λ_A. Figure **??** shows a typical calorimeter unit cell. The electric field is established by grounding the metal absorber plate and

Figure 2.3: Calorimeter Side view

connecting the resistive surfaces of the signal boards to a positive high voltage(typically 2.0 - 2.5 kV). The drift time of the electron between gap is about 450 ns. The thickness of the gap was determined to be large enough to observe minimum ionizing particle signals and to avoid fabrication difficulties. DØ calorimeter is using different absorber plate materials in different locations. The EM modules for both CC and EC have nearly pure depleted uranium and its thickness were 3 mm and 4 mm respectively. The fine hadronic modules have 6 mm thick uranium-niobium(2 %) alloy. The course hadronic modules used relatively thick (46.5 mm) plates of copper for CC or stainless steel for EC. Signal boards were constructed by two separated 0.5 mm thick G-10 sheets with high resistivity carbon-loaded surface in outside.

The determination of the pattern and sizes of readout cells very crucial in calorimeter construction. The typical transverse size of showers is 1$\sim$2 cm for EM showers and 10 cm for hadronic showers. We defined the variable $\Delta \mathrm{R} = \sqrt{\Delta\eta^2 + \Delta\phi^2}$. Since the consideration of ΔR of the typical size of parton jets is 0.5 and the finer segmentation than this will help to probe the shape of jets, each section(EM, fine hadronic and coarse hadronic sections) has longitudinal subdivisions to help distinguish electron and hadrons using longitudinal shower profiles. DØ calorimeter has a 'pseudo-projective' set of readout towers, with each tower subdivided in depth. The term pseudo-projective is introduced because of the fact that the *centers* of cells of increasing shower depth lies on rays projecting from the center of the interaction region but the cell boundaries are aligned perpendicular to the absorber plates. Figure **??** shows the side view of the DØ calorimeter segmentation pattern. EM modules consists of 4 separate depth layers in CC and EC. The first two layers help to measure the longitudinal shower development near the beginning of the showers where photons and π^0s differ statistically with 2 radiation lengths(X_0) thick. The third layer of EM modules aims to obtain the maximum EM shower energy deposits with twice finely segmented in both η and ϕ to provide more precise location of EM showers and the fourth layer completes the EM coverage with 20 X_0. Typical fine hadronic modules are segmented 3 or 4 layers and coarse hadronic modules consists of one or three layers. The transverse size of towers in both EM and hadronic modules are $\Delta\eta = 0.1$ and $\Delta\phi = 2\pi/64 \approx 0.1$.

The central calorimeter(CC) involves three concentric cylindrical shells in Fig. **??**. The inner ring contains 32 EM modules and 16 fine hadronic (FH) modules surrounds the inner ring. The outer ring contains 16 coarse hadronic(CH) modules. Each EM modules have 2.0, 2.0,6.8 and 9.8 X_0 and the total number of signals for the 32 modules is about 10,400 with 24 $\Delta\eta = 0.1$ towers along the 260 cm length and total 20.5 X_0 and 0.76 λ_A with weight 0.6 metric tons. Each FH modules have 1.3,1.0 and 0.9 λ_A and provide 3500 signals with weight 8.3 metric tons. The CH modules contain only one depth segment of 3.2 λ_A and provides 770 signals with weight 7.2 metric tons. The total weight of the CC modules and their support structure is 305 metric tons with 26 metric tons of liquid argon.

The end calorimeters (ECN and ECS) located in each side of the CC and it contains four module types as shown in Fig. **??** and Fig. **??**. ECEM modules contains four readout sections with each 0.3,2.6,7.9 and 9.3 X_0 and each ECEM provides 7488 signals with weight 5 metric tons. The outer radii varying between 84 and 104 cm with inner radius of 5.7 cm. With the material of the cryostat wall brings the total absorber for the first section up to about 2 X_0. The two cylindrical ECIH with inner and outer radii of 3.92 and 86.4 cm contains the fine hadronic section and coarse hadronic section. The fine hadronic section involves four readout sections with each containing sixteen 6 mm semicircular uranium plates with 1.1 λ_A each. The coarse hadronic section has a single readout containing thirteen 46.5 mm stainless steel plates with 4.1 λ_A. The full ECIH module weight 28.4 metric tons and provides 5216 signals. Each of the ECMH modules contains 4 fine hadronic(uranium) sections of about 0.9 λ_A each and a single coarse hadronic(stainless steel) section of 4.4 λ_A with weight 4.3 metric tons and 1856 signals. The ECOH modules consists of stainless steel plates inclined at an angle of about 60^o with respect to the beam axis as shown in Fig. **??** with weight 5.5 metric tons and 960 signals. The total EC calorimeter weighs about 238 metric tons.

The newly designed calorimeter electronics is implemented to accommodate the Run II bunch spacing(396 ns and later 132 ns) and to maintain the Run I noise and pile-up performance which implied the necessity to store the analog signal for 4 μs, allowing the formation of the L1 trigger decision and to generate a separate, fast trigger signal for the calorimeter to be included in the L1 trigger level, and to adopt new strategies for the baseline substraction.

To minimize the sensitivity to reflections, new impedance-matched 30 Ω signal cables are used from the former 110 Ω cables between the detector and the low-noise preamplifiers. The replacement cable lengths were tuned to minimize the spread in the total cable length from the readout cells to the preamplifiers to reduce the effects of the signal timing. A fast trigger signal is then produced, whereas for the energy measurement a shaping of 400 ns is applied and Switched Capacitor Arrays(SCA) store the signal for up ≈ 4 μs until the L1 trigger decision is received and the Base-Line Subtractor(BLS) evaluates the zero-level three bunch crossings before the actual signal. New and additional controllers were used to coordinate the 144 analog samples per channel and supplementary SCA provides additional buffering of the signal waiting L2 trigger decisions. New calibration system accommodates the timing constraints and improve the precision and new readout electronics are used to monitor the liquid argon purity and temperature. The new charge-integrating preamplifier is a hybrid circuit on ceramic and has a high DC open-loop gain and input impedance, tuned to 30 Ω to match the input cables, and low input bias current. Two input low-noise jFETs (Toshiba 2SK369) in parallel compensate for the higher electronic thermal noise due to the shorter shaping times and to minimize reflection on the 110 Ω cable from the BLS input, the preamplifier out is terminated and back-terminated.

2.2.3 Muon Detectors

The muon system has been upgraded for DØ Run II physics goals with the higher event rates and backgrounds expected in Run II. The physics motivations for going to the highest luminosity are to study low cross section, high-p_T processes, such as top and WZ, and to search for new phenomena. To maximize the acceptance for muons from these processes, it is important that sufficient detector coverage and an efficient, unprescaled trigger. It is required that $\mid \eta \mid$ coverage to ~ 2 for DØ's physics goals, which is satisfied with new muon system design.

Triggering in the high rate environment of Run II needed the use of fast trigger elements with good time resolution. In the central region, the proportional drift tubes(PDT) is used since Run I because the maximum drift time in the existing PDTs of 750 ns exceeds the Run II bunch spacing of 396 or 132 ns and scintillators will provide the necessary time stamp but the front-end electronics have been replaced to support deadtimeless operation. The central PDT's a layer of scintillation counters has been added in just outside the calorimeter to provide the time information and match the muon tracks in the CFT, and consists of three layers to reduce hit combinatorics. The scintillator time resolution is 1.6 ns and it provides the rejection of out-of-time backgrounds. For high luminosity(high event rate) with harsh radiation environment and full coverage of pseudorapidity range in Run II the forward proportional drift tubes(PDTs) has been replaced with mini drift tubes(MDTs). The forward muon system consists of three layers of MDTs and three layers of scintillation counters covering $1 <\mid \eta \mid< 2$. The MDTs consist of 1 cm cm cells produced in 8-cell extrusions using a fast gas (90% CF_4 - 10%CH_4) of the drift time of 60 ns. The shielding consists of 39 cm of iron as a hadron and electromagnetic absorber and 15 cm of polyethylene to absorbs neutrinos due to the high hydrogen contents and 15 cm of lead as a gamma rays absorber to reject the backgrounds from the scattered p and $\overline{p}$ fragments interacting with the calorimeter, low-eta quadrupole magnets and beam halo interactions.

2.2.4 Luminosity Monitor

The Luminosity monitor(LM) is designed to provide a precise measurement of the rate for non-diffractive inelastic collisions with high efficiency for making an accurate determination of the Tevatron luminosity at DØ. The secondary purpose for luminosity monitor is to provide diagnostic information regarding accelerator performance. In addition, the precise time-of-flight resolution allows to determine the beam-beam interactions from the principal background from the beam halo and measure the position of the primary interaction vertex and detect multiple interactions. The luminosity monitor provides trigger signals to identify beam crossings with a single $p\bar{p}$ interaction with large η trigger coverage for hard diffractive and rapidity gap triggers.

DØ luminosity monitor for Run II employs plastic scintillaters readout via photomultipliers. There are 24 wedges arrayed around the beam pipe as shown Fig. **??** and mounted on the inside edge of each end calorimeter cryostats at z $\approx$ $\pm$ 140 cm that cover the region $2.7 <| \eta |< 4.4$. The photomultiplier tubes have a relative gain of > 10000 at 1 Tesla due to the fact that the counters are located in a region where the nearly axial magnetic field of $\approx$ 1 Tesla produced by solenoid. The LM was designed to have the time-of-flight resolution of $\approx$ 200 ps.

The LM uses the time difference between signals produced by the north and south detectors to differentiate between collisions(luminosity) and beam losses(halo). Using the Run I NIM based FastZ modules, signals from wedges in each half of the detector are summed together and used as inputs to the FastZ. Then FastZ compares the time difference between the summed north and summed south signals to independently identify luminosity and halo. Protons travel clockwise around Tevatron so that a muon produced by an errant proton(i.e. proton halo) will be detected in the north LM first then $\sim$ 9 ns later it will pass the south LM. The antiprotons travel counter-clockwise around Tevatron, so that the anti-proton halo will be detected in the south LM, then in the north LM. However particles produced in collisions between protons and antiprotons in the DØ interaction region will detected in the north and south LM at approximately the same time. The difference of detection in between north and south LM is key to identify the Z of the interaction.

The FastZ modules use a set of gates to distinguish between collisions and halo and determine the Z position of the interaction with this time difference. Typical resolution is ≈ 6.25 cm in Z. All of these signals including luminosity, proton halo, anti-proton halo and the Z position of the interaction is digitized in five bits and sent to the Trigger Framwork as And/Or term for use in Level 1 trigger decisions which will be described in Chapter 3.

The luminosity block is the fundamental unit of time for the luminosity measurement and each block is indexed by the luminosity block number(LBN), which monotonically increases throughout Run II. The LBN is incremented upon run or store transitions, TFW or SCL inits, by request, or after 60 seconds have elapsed and the time span was chosen based on the numerous constraints in the luminosity, trigger, and DAQ systems. This time period is short enough so that the instantaneous luminosity is effectively constant during each luminosity block and raw data files(partitions) are opened and closed on LBN boundaries. The luminosity calculations are made independently for each LBN.

Chapter 3

Data Acquisition

3.1 Trigger

The trigger system in DØ detector upgraded significantly to enhance data acquisition and triggering to operate in the high luminosity ($L = 2 \times 10^{32} cm^{-2} s^{-1}$), high rate environment (7 MHz or 132 ns beam crossings) of the upgraded Tevatron accelerator. The Run I DØ trigger system (1992-1996) consisted of two hardware triggers and one software trigger [8] to select the 3.5 Hz of events for further offline processing from the approximately 0.5 - 1.0 MHz collision rate. The first hardware level was L0 which is a schintillator hodoscope trigger sensitive to all inelastic collisions and the second hardware trigger was L1 which gave a decisions in 3.5 μs based on fast sums from calorimeter and muon detectors. The L3 was software-based filters in a farm of approximately 50 processors. Between L1 and L3, there was a third hardware trigger, L2, refined the calorimeter-based trigger for electron candidates by examining the shape of the energy deposition and refined the muon trigger by using finer granularity hardware information. L2 interrogated only subset of the L1 accepts and inhibited data taking while examining the event and the L1/L2 event accept rate was 150 Hz where the event sizes were typically 450 kbytes. These trigger system operated with overall data-collection efficiency of 90%.

In Run II, a ten-fold increase of luminosity, to $L = 2 \times 10^{32} cm^{-2} s^{-1}$, and a forty-fold decrease in the time between beam crossings from 4 μs to 132 ns require significant upgrade of the entire trigger system. Furthermore for these high rate demands of Run II, the DØ trigger was improved in three basic ways. To increase rejection, the upgraded trigger will include several new tracking detectors: the fiber tracker(CFT), the central preshower(CPS) and the forward preshower(FPS) and upgraded muon detection system. For the L2 system which will examine all events, we used several new detector-specific preprocessing engines and a global stage to test for correlations between L1 triggers. Finally the computational needs of L3 system are strengthened by the bandwidth and processor improvements. In Addition the L0 system is substantially upgraded and used primarily as a luminosity monitor.

3.1.1 Level 1

The upgraded L1 trigger detectors include CFT,CPS,FPS, the calorimeter (CAL), and the muon scintillators (SC) and tracking chambers(MDT and PDT) as shown in Figure 3.1. The CFT is innermost L1 trigger detector which surrounded by a superconducting magnet, preshowers, CAL and the muon system. The muon system includes a layer of tracking and scintillator planes, a second magnetic spectrometer, and further layers of tracking and scintillator planes in order of increasing radii. The calorimeter, fiber tracker and preshower detectors will cover electron trigging for $|\eta| < 2.5$ and the fiber tracker and muon systems will provide muon triggering in the region $|\eta| < 2$.

Figure 3.1: L1 and L2 trigger elements and the horizontal arrows denote information flow

The L1 triggers associated with each of the trigger detectors examine each event and reports their findings or trigger terms to the L1 Framework(L1FW) and each front-end digitizing crate includes sufficient memory to retain data from 32 crossings which ensures deadtimeless operation for 7 MHz(132 ns crossings.) The L1FW will support 128 unique L1 trigger bits and each bit is pre-programmed to require a specific combination of trigger terms. A series of field programmable gate arrays (FPGAs) will examine the list of terms collected from the luminosity monitor, CFT/CPS,FPS,CAL and MUON L1 triggers to determine if a specific L1 bit has been satisfied and issues an accept and the events data is digitized and moved from the pipeline into a series of 16 event buffers to wait for the L2 trigger decision. L1 accept rate is 10 kHz and the trigger decision will be issued 4.2 μs after a beam-beam crossing.

The L1 calorimeter trigger is not changed from Run I. The local energy deposition and global calorimetric characteristics can generate a trigger and the calorimeter is segmented into trigger tiles of $\eta \times \phi = 0.8 \times 1.6$ and trigger towers of $\eta \times \phi = 0.2 \times 0.2$ covering $\mid \eta \mid < 4$ where ϕ is the azimuthal angle. A calorimeter trigger requires E_T above a preset threshold in one or more calorimeter trigger elements and a total of sixteen threshold sets are available. Additional trigger terms are provided for global quantities or trigger tower sums such as total E_T, total energy, and missing E_T.

The trigger scheme for the fiber tracker is based on the hit patterns in the axial fibers since a charged particle will bend in the azimuthal direction due to the central magnetic field and a charged particle will follow a curved trajectory from the view along the beam. The magnitude of the curvature depends inversely on the particle momentum. Each of the CFT axial fibers are read out with visible light photon counters [9] and the counters outputs are discriminated for triggering and digitized for readout. The trigger signals are collecting by a series of large field programmable gate arrays(FPGA) resident on VME cards and this FPGAs are preloaded with the appropriate logic to form eight-fold coincidences from hits in the eight CFT axial threshold. A trigger will be generated by any hits in pattern consistent with track momentum above a software settable threshold and the lowest P_T threshold is in the 1.5-3.0 GeV range and is limited, in part, by FPGA capacity within 600ns decision time. The trigger data is sent serially at 424 MHz to a CFT trigger manager(CFTTM) and to the MUON L1 trigger system. There is a limit of six CFT trigger candidates per sector and each trigger candidate will be identified by momentum, charge, azimuth in the last axial layer, the presence of preshower energy deposition above threshold, and isolation. Because only axial fibers contribute to the trigger no rapidity information is available for transmission. The CFTTM will provide sixteen L1 terms: the number of tracks above each of the four thresholds, the number of isolated tracks above the four thresholds (no other tracks within one sector), the number of tracks above the four thresholds with a coincident CPS energy deposition, and the number of isolated tracks above the four threshold with CPS deposition.

The central L1 muon trigger detectors consist of a scintillation counter layer segmented in azimuth and rapidity and a layer of proportional drift tubes(PDT) before the muon spectrometer, two layers of PDTs after magnet, and an outer layer of cosmic ray veto scintillation counters. The forward L1 muon detectors include three layers of pixel scintillation counters segmented in azimuth and rapidity and three layers of mini-drift tubes (MDTs). The CFT is used for integral component of the L1 triggering scheme for both the central and forward regions. Central fiber trigger tracks, scintillation counter hits and wire chamber centroids are sent to the trigger hardware via Gbit/s serial links from AMCC over coaxial cable.

3.1.2 Level 2

In L2 trigger the accept event rate will be reduced to 10 kHz by roughly a factor of ten within 100 μs using multi-detector correlations of objects. There are two distinct L2 stages are planed and the first stage, or preprocessor stage, prepares data from each L1 trigger for use in the second or global processor stage. In the global processor the combination of L1 trigger objects from different detectors is being used and the relationships between L1 and L2 trigger elements are shown in Figure 3.1. A L2 Framework is utilizing the same FPGA logic as the L1 Framework and will coordinate the operation of L2 and report trigger decisions to L3.

Upon recept of a L1 accept from the global processor, L2 will initialize detector readout and move the event data into eight transfer buffers. There is a one-to-one mapping between the L1 and L2 bits. The global processor receives preprocessor information on data operating at 320 Mbytes/s within 75 μs trigger decision time which are based on correlations amongst multiple detector systems, such as spatial correlations between track segments, preshower depositions, and calorimeter energy depositions for electron candidates.

The operation of the overall trigger system, and L2 especially, has been extensively implemented using the RESQ [10] simulation package and the deadtime and time budgets are evaluated with the constraint that a maximum of 16 events may reside in the L2 trigger input buffers, preprocessor, or global processor. According to the simulations the system deadtime for highest data rates expected in the upgrade is 5% or less for preprocessor and global processor timing budgets of 50 and 75 μs. Additionally the timing budgets has a relatively weak dependence with the deadtime. The event rate reduction afforded by L2 has been studied using detailed GEANT detector simulations. The event sample generated with ISAJET includes multiple hadron-hadron interactions within a single beam crossing and 2500 Hz input rate can be reduced to a 500 Hz output rate for full mix of high P_T triggers.

The Calorimeter preprocessor includes an electromagnetic preprocessor, a jet preprocessor, and a missing E_T preprocessor. The preprocessor reads the full array of 1280 trigger tower E_Ts for both electromagnetic and the electromagnetic plus hadronic sums and clustering algorithms build electron or jet candidates and calculate their position and energy and test them for shape and transverse energy requirements. With information on the L1 triggers, the tower information results in a minimum of 4 kbytes/event, or 40 Mbytes/s.

The Muon identification has been improved using the muon preprocessor by repeating the L1 muon trigger calculation but more precise transverse momentum, rapidity, azimuth, and quality for the muon candidates. Each muon chamber and scintillator detector provide information to the L2 trigger and L2 trigger repeats the L1 calculation but incorporating calibration information and more precise timing information from scintillator. With input rate of 10 Kevents/s the data, averaging 5kB/event, is spread across roughly 140 sources on fast 160 Mbit/s serial links. Using a massively parallel architecture the muon preprocessor provides a deterministic algorithm with execution time independent of the number of detector hits and the geographic segmentation of the detector allows reduction of the track finding into small well-defined regions, one per processing element. Each of the many parallel processing units execute the same algorithm concurrently with the translational symmetry of the detector elements.

Two central tracking preprocessors are implemented in L2 trigger system. A list of trigger tracks is assemble with P_T or azimuthally order and transmitted to the global processor. The FPS preprocessor computes the azimuth and rapidity of forward electron candidates to improve forward electron trigging. The CFT and FPS candidates with calorimeter electron candidates are correlated with the global processor. A silicon impact parameter trigger(SVT) is utilizing the hits from the million channel silicon vertex tracker, located inside the CFT, to search for track vertices some distance from the interaction vertex, these secondary or displaced vertices are characteristic of long-lived particles and can be used for heavy quark tags.

3.1.3 Level 3

The Run II L3 system has been upgraded from the existing data acquisition and trigger and the enhanced system have an input rate of 1 kHz and a 50 Hz accept rate with further increases in bandwidth where the event size is typically 250 kbytes.

Figure 3.2: Level3 architecture

The increased rate can be achieved with a highly parallelized data pathway and fast processors. Both Run I and Run II systems are characterized by parallel datapaths which transfer data from front-end crates to a farm of processors and each event is examined by a processor with a suite of filters. Due to the these fundamental similarities from Run I, the Run II L3 can utilize much of the Run I cable plant and infrastructure.

Each front end crate generates one block of data per event and these data blocks move independently through data system and are recombined into single events at their assigned L3 processor node. This system makes its routing decisions based on information contained in the data block header, L2 trigger information, and preloaded routing tables and data blocks from multiple events flow on the datapaths at the same time. Figure 3.2 shows the upgraded Run II data acquisition path.

The accepted L2 digitized data will be loaded from the L3 transfer buffers onto one of 16 high speed data pathways (48 mb/sec) by driver modules which sit in VME front-end crates. The various cables are arranged to distribute the data load evenly and the data cable carries the data to a VME Receiver Collector, the VRC. The VRC sends the data from either of two data cables in fiber using low level Fiber Channel hardware, to the L3 Farm Segment Controllers(SC's) for long-haul transmission between the DØ counting rooms and each fiber is connected to each SC in a daisy chain fashion. With L2 accept, the Event Tag Generator uses trigger bits to assign an event to a specific event class and a SC accepts the tag and assigns the event to a specific L3 node in the attached segment. Each SC examines each passing data block and extracts those data blocks belonging to an event assigned to a node on that SC and the remaining data blocks are passed onto the next SC. Data blocks not extracted by the last SC are returned to the VRCs for recirculation as a self limiting rate mechanism. Data blocks of the SC's move into processor nodes through multi-port memories for final event assembly. With additional controllers and processors the system bandwidth can be increased to 10 kHz. Using high level programming or event filtering the rate rejection is obtained by filtering each event with "physics tools" and these tools will have access to all event data to search for electron, muon, and jet candidates as well as interesting event topologies. Finally any event meeting filter requirements is transferred to tape storage for later offline reconstruction.

Chapter 4

Monte Carlo Simulation Data Reconstruction

4.1 Monte Carlo Simulation

For the study of signal and background processes, We used the Monte Carlo simulation techniques. Monte Carlo simulation consists of 4 stages. The first stage is event generation which simulates the particle collisions. The second stage is detector response simulation where the simulation of the interaction of the particles passing through the detectors is done and we used DØGSTAR(DØ GEANT Simulation of the Total Apparatus Response program). Once the simulation has been done, we need to digitize the information of simulation to make a reconstruction in d0reco which is used for data reconstruction. We used d0sim package for this stage and finally for the trigger study, we used trigger simulation.

4.1.1 Event Generation

For the simulation of hadron-hadron collisions, we have numerous generators but for this study we used phythia [11] for $t\bar{t}$ generation. vecbos or alpgen for background.

4.1.2 Detector Simulation

The DØ GEANT Simulation of the Total Apparatus Response(DØGSTAR) package

4.2 Data Reconstruction

The event passed by L3 trigger consists of raw information which are hits in tracking system and digitized counts in calorimeter and so on. These event will be stored in SAM(Sequential data Access via Meta-data). Sam is a file based data management and access layer between the Storage Management System and the data processing layers. The goal of this SAM is to optimize the use of data storage and delivery resources, such as tape mounts, drive usage, and network bandwidth. In order to facilitate this goal, the primary objectives are:

1. Clustering the data onto tertiary storage in a manner corresponding to access patterns, 2. Caching frequently accessed data on disk or tape, 3. Organizing data requests to minimize tape mounts, and 4. Estimating the resources required for file requests before they are submitted and, with this information, making administrative decisions concerning data delivery priority.

In addition, it is desired to unload the burden of individual file tracking from the analysis physicists, and place it onto the data management system. This is an added bonus integrated into the SAM system.

This raw data need to be convert to objects like electrons, photons or jets in which physicist is interested. We called this process a reconstruction and DØ has performed this process by D0Reco which consists of huge separated programs. Each program was made using c++ language for object oriented programming and each program is maintained and upgraded by each institution. Because reconstruction algorithm has been developed to identify the objects like jets, electrons, photons or muons better.

This d0reco also utilizes the information of detector survey and calibration to make the objects. The output of d0reco is a set of files written in DØ Object Management(DØOM) format. The size of DØOM files for an event is quite large, typically 2Mbyte/event and it contains raw data information with reconstructed object information. Previous the root file format was available since the beginning of the Run but with expected huge amount of data due to the luminosity upgrade, the DØOM format is converted to thumbnail format which is compress size and contains minimum amount of information, typically 15kbyte/event compared to 100kbyte/event in ROOT format.

The basic reconstruction procedure is following. The first it collects hit information which was digitized signals from the sense wires of the tracking detectors and converts to spatial locations in physics coordinates. The energy deposition is collected using calorimeter cells information. The tracks for events is constructed using this hit information from trackers and the clustering is formed based on the information of energy deposition in calorimeter cells. Using this tracks and calorimeter cluster, the primary and the secondary vertex is constructed. Using this vertex, tracks and clustering information, the objects are identified as jets, electron, photons and muons which we called particle identification based on selection criteria for each object.

The calorimeter hits are converted to raw digitized cell energy information.

The calibration and corrections are applied by cell- by-cell variations based on the gain and pedestals. The transverse energy is calculated using the cell energies and the position of interaction vertex. The towers are defined by the cells with the same η and ϕ and used to identified the objects like jets, electron or photons.

The hits and time information in muon detectors are converted to muon tracks based on the three dimensional position information. tracks are found by fitting a group of hits in straight line and we called this as a local muon and if this local muon is matched with global fitting using tracks from central detectors and the event vertex, we called it as global muon which provided the improved momentum resolution. With this momentum, we can measure the loss of energy in the calorimeter.

The jet algorithm is consists of preclustering and cone clustering. In the preclustering stage, the calorimeter towers are ordered in E_T and in the beginning of the highest E_T a preclustering is formed from all adjacent towers with $\Delta\eta < 0.3$, $\Delta\phi < 0.3$ with all towers of $E_T > 1$ GeV. The axis of the corresponding jets are defined by the E_T weighted centroid of each precluster. The cone clustering is formed using all towers within a radius of R in the $\eta - \phi$ space with this candidate preclusering jet axis. Using this cone, the new jet centroid as well as the new jet axis is calculated repeatedly until it is stable. Normally towers should not be shared among jets but during cone clustering few towers can be shared among different jets. If the fraction of the total energy which is shared between them is more than 50% of the E_T of the softer jet, then the two jets are merged and jet axis is recalculated. Otherwise they are split into two jets with each tower being assigned to the closest jet. Due to the random noise fluctuations an E_T threshold of 8 GeV imposed.

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